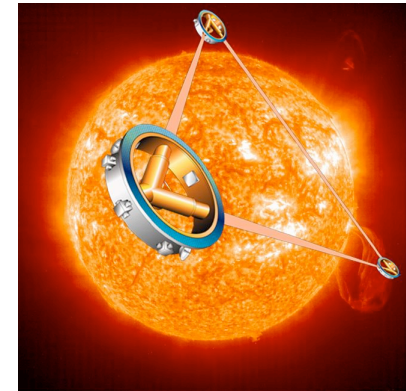


# Solar, cosmic ray and environmental physics (SCoRE) for, and with, LISA



Diana Shaul, Imperial College, on behalf of the SCoRE collaboration:

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# Aims of SCoRE

- What can we do for LISA?

- Improved characterisation of environmental disturbances (e.g. particle fluxes)
  - ⇒ Improve disturbance estimates
  - ⇒ Optimise disturbance elimination
  - ⇒ Improve anomaly identification

Part 1 of talk – progress to date – mainly on SEP and GCR flux characterisation

- What can LISA do for us?

- Long-baseline 3 spacecraft configuration => unique opportunity for studies of solar, cosmic ray and environmental physics.
- “Free” extra science from LISA

Part 2 of talk

**What we can do for LISA**

# SEP and GCR flux characterisation

- SEP and GCR flux transfer momentum, heat & charge to TMs
- Main disturbance = Coulomb & Lorentz interactions of charged TM with sensor & IMF

=> Acceleration noise, Stiffness modification, coherent Fourier components

- **Disturbance characteristics & magnitude depend on charging environment**

- **Solar Energetic Particle events**

- Sporadic; Duration ~ 1 day – 1 week
- ~100 % - 70000 % (rare) (Araujo et al 2005; Vocca et al 2004 & 2005)
- **Will discuss expected frequency, duration and strength of events**

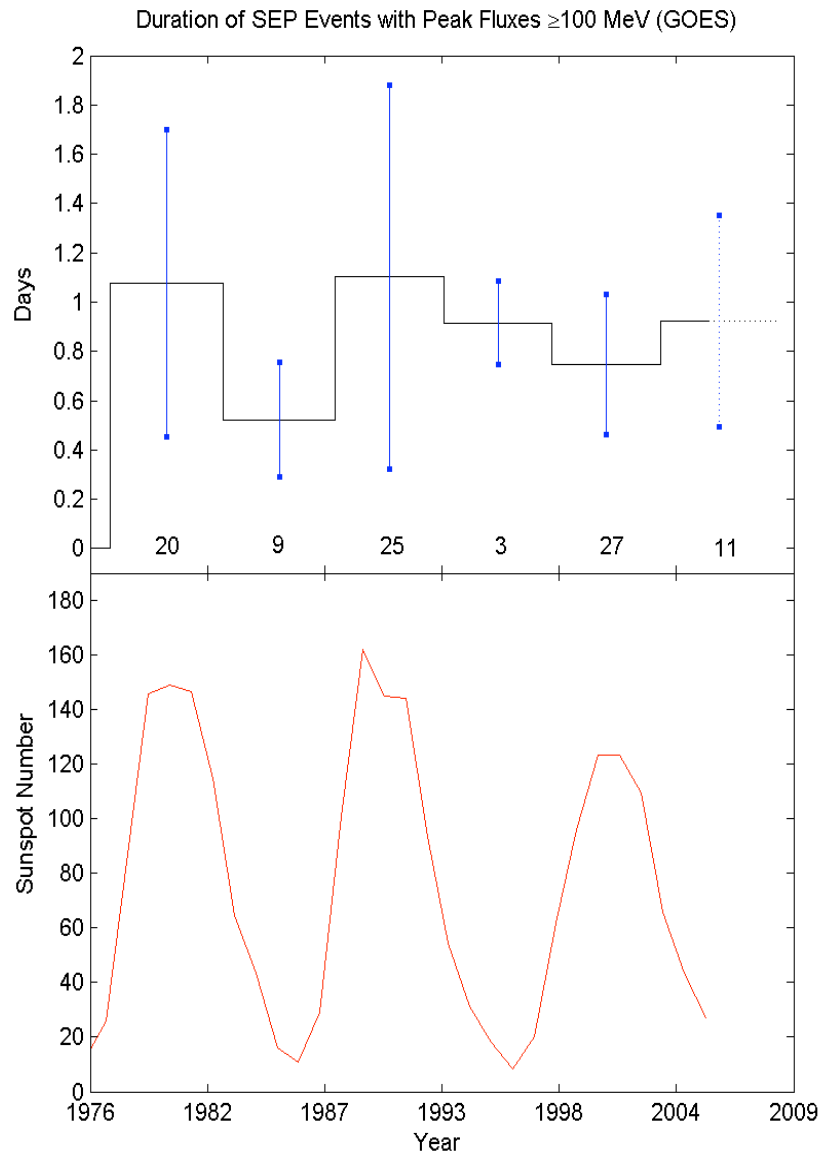
- **GCR fluctuations from:**

- |  |  |
|--|--|
| <ul style="list-style-type: none"><li>– Solar Cycle<ul style="list-style-type: none"><li>• 11 year period (approximate!)</li><li>• 50% difference in solar min &amp; max rate (Araujo et al 2005)</li><li>• Gradual &amp; sharp changes possible</li></ul></li><li>– Solar rotation<ul style="list-style-type: none"><li>• ~ 27 day period</li><li>• ~ 1 – 5 %</li></ul></li></ul> | <ul style="list-style-type: none"><li>– Forbush Decreases<ul style="list-style-type: none"><li>• ~ few – 35 %</li></ul></li><li>– Other modulations in GCR:<ul style="list-style-type: none"><li>i. mHz fluctuations</li><li>ii. ~ few % in ~ week</li></ul></li><li>– <b>More on this later</b></li></ul> |
|--|--|

# **SEPs:**

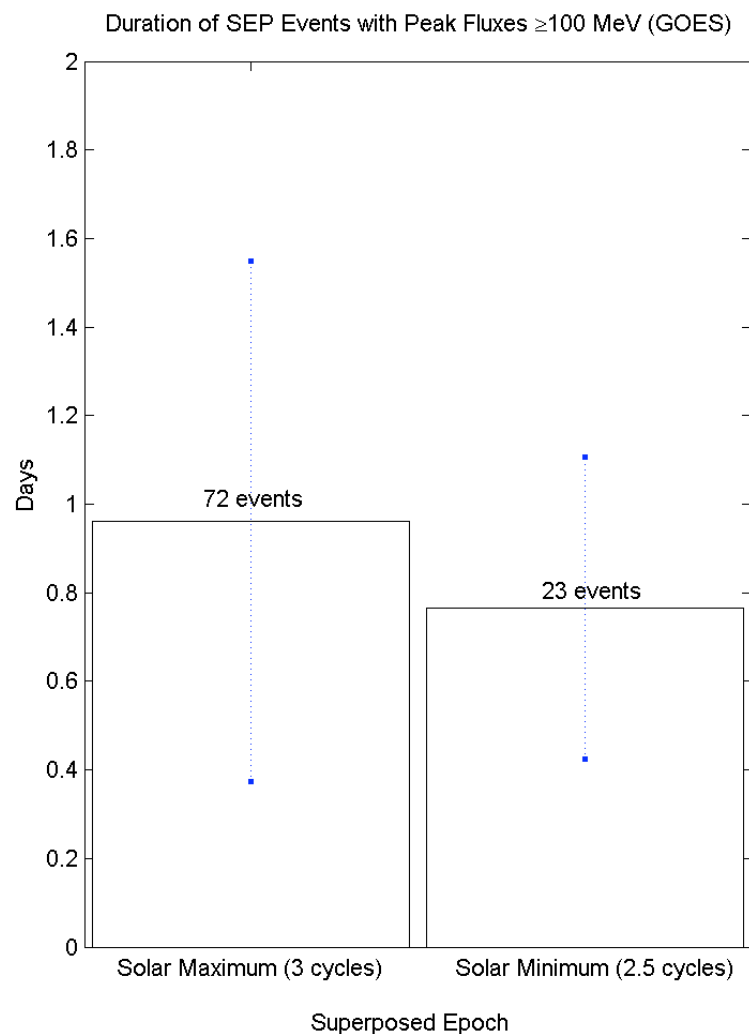
**Past, present and future**

# SEP Event Durations (1976-2005)



- GOES data at 1 AU peak fluxes  $>100\text{MeV}$
- Means include time above 10 MeV per event (conservative for LISA)
- At solar max, more variability
- At solar min, durations and standard deviations lower, but statistics poorer
- Dashed lines = incomplete analysis for this solar min - start 2005
- Data from lower energy SEP events  $\Rightarrow$  mean event duration increasing for successive solar minimum intervals - may be due to ascending phase of Gleissberg cycle (Ongoing analysis).

# SEP Event Duration Averages

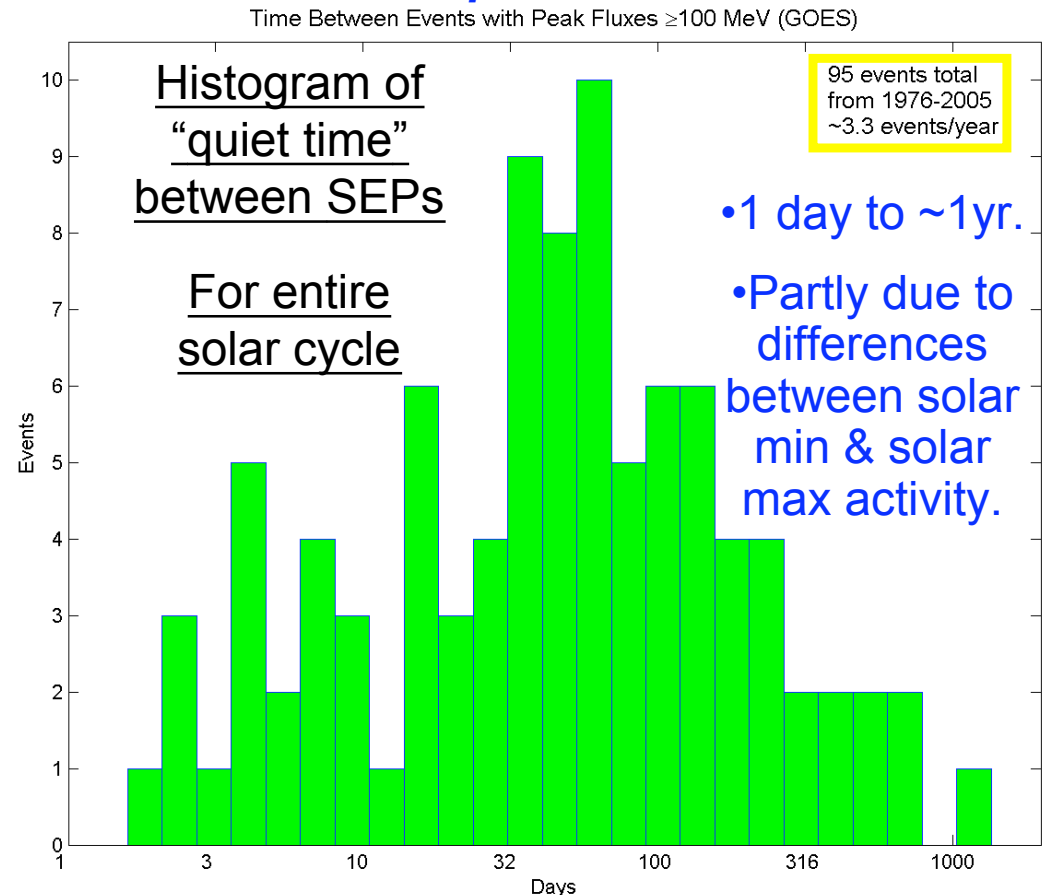
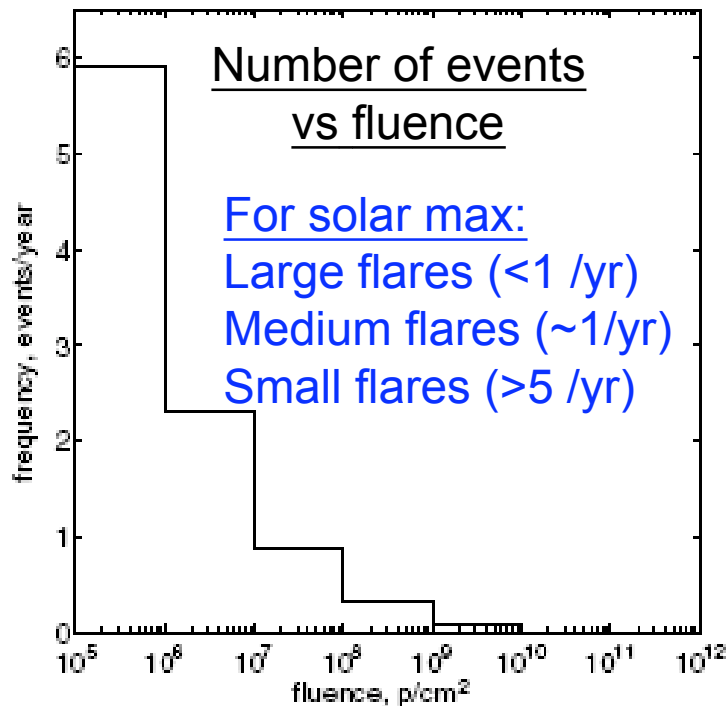


- SEP event durations (from prior slide) in superposed epoch analysis
  - Near 3-fold improvement in statistics.
- Overall, mean event duration is just under 1 day +/- \_ day at solar max and +/- 1/3 day at solar min.

# SEP rates

**GOES data –extend study & will test predictions**

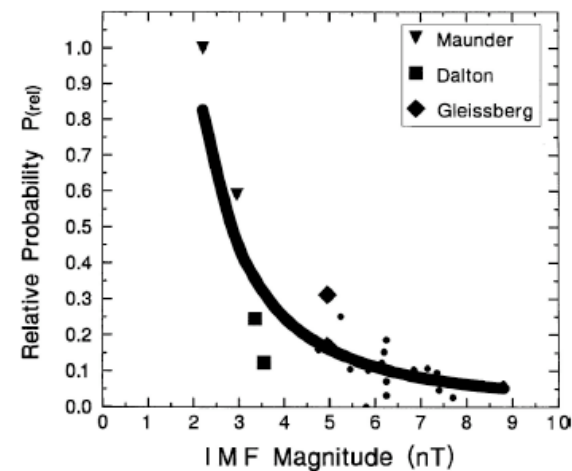
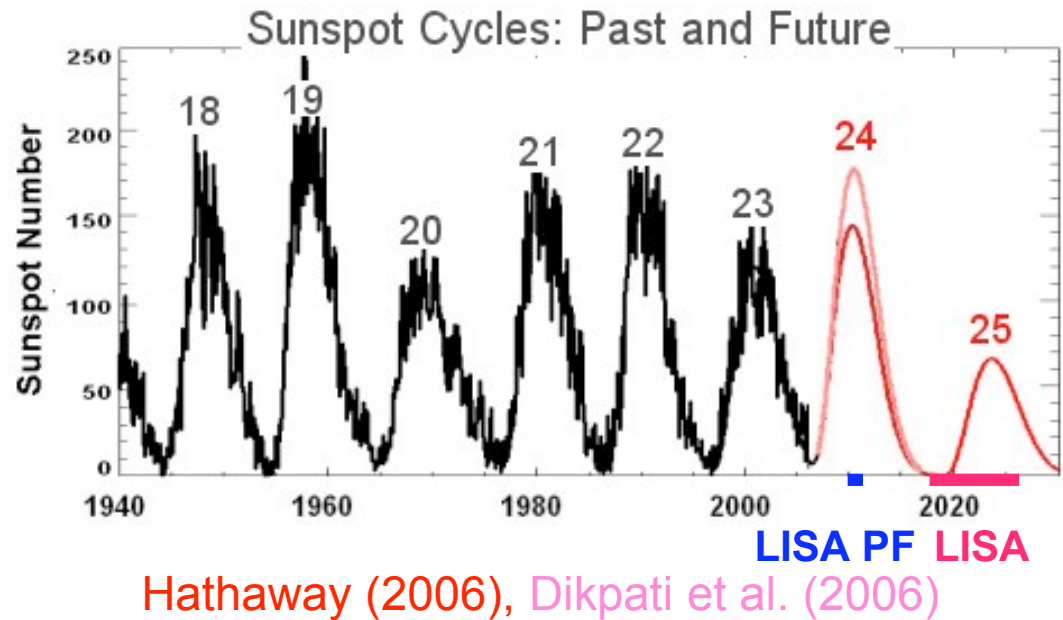
Initial study based on *Nymmik model* (Araujo et al 2005)



- Swimm et al (2006): 6-hour averaged data (durations & “quiet time”) = Poisson distributions
- Ongoing analysis of data to improve resolution of solar max and solar min & quiet time on shorter time scales

# Solar & Gleissberg cycles

- SEP frequency has a stronger dependence on the 80-100 year Gleissberg cycle than sunspot cycle (McCracken et al., 2004) - predicted to be entering ascending phase.
- CME frequency  $\propto$  sunspot number and CME speed (shock acc<sup>n</sup>)  $\propto$  SEP intensity.
- SEP probability  $\propto$  IMF B<sup>-2</sup> (McCracken et al., 2004)

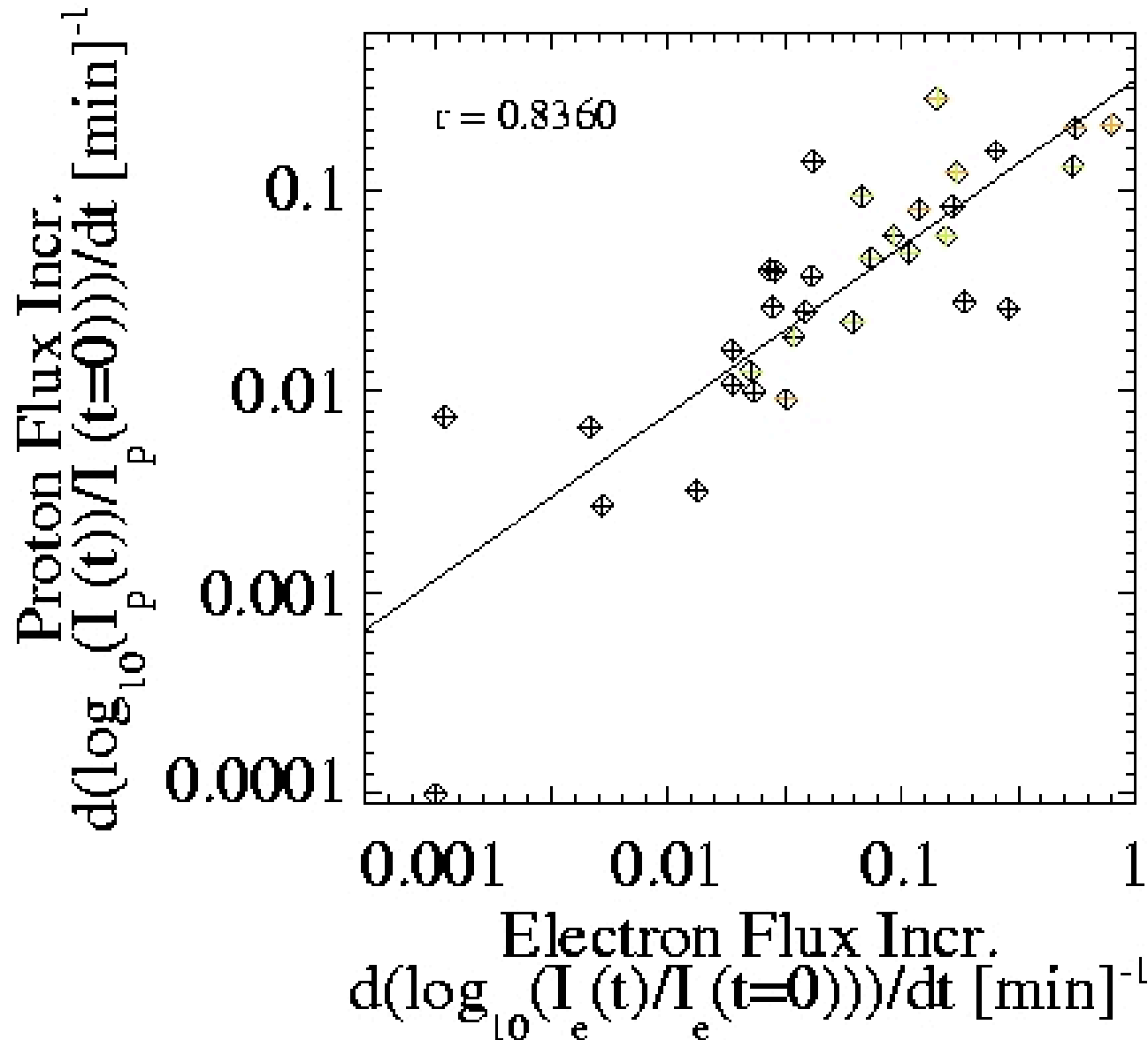


McCracken et al. (2004)

# The bottom line...

- Hard to make definite predictions...
- Some evidence of increase in large SEP events, indicative of approaching Gleissberg maximum and increased probability of large fluence events.
- Cycle 24 may be strong -> produce more and faster CMEs, cycle 25 weaker - potentially good news for LISA, although large events tend to cluster in descending phase of the solar cycle.
- A more active cycle will probably also imply stronger IMF so the two effects may balance - predictions of IMF strength for the next cycle don't currently exist - worth pursuing.

# Early warning system



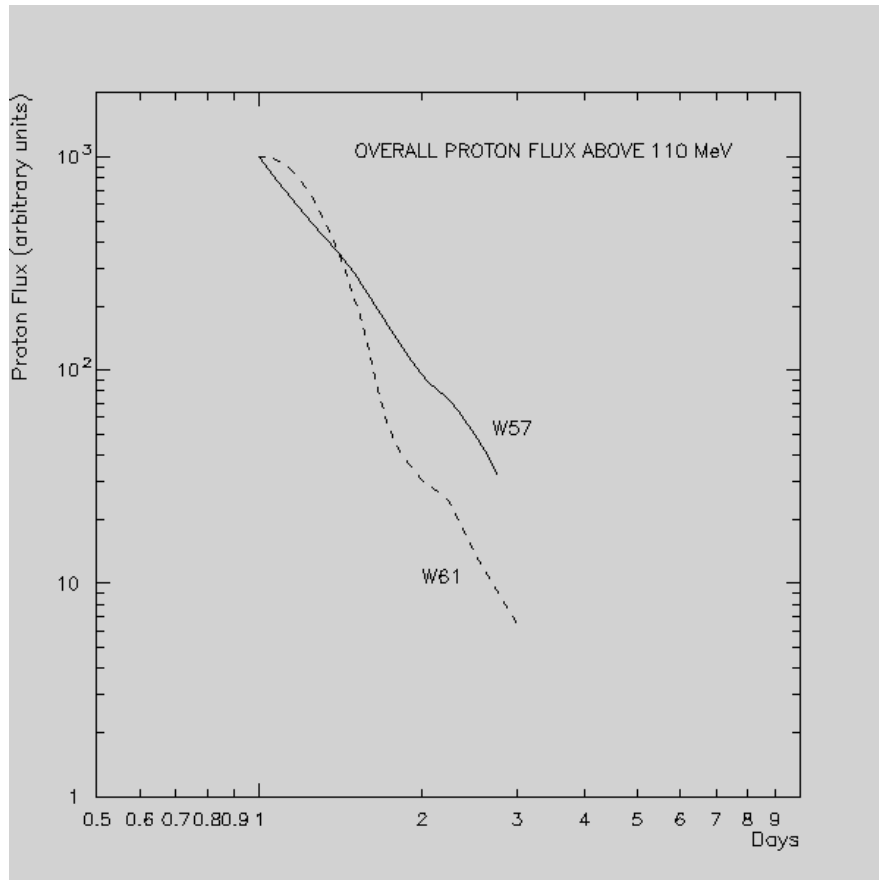
Correlation of fast electron onset parameters with proton/ion onset for the strongest solar energetic particle events (data from 1998-2002).

Relativistic electrons provide a means to predict upcoming ~100 MeV proton event fluxes for LISA with advance warning time of 5-10 minutes.

# Particle Detector Requirements

- Four solid-state detectors stacked in a telescope with pulse-height analysis (150um, 300 um, 500 um, 500um thickness)
- Anti-coincidence surrounding the SSDs for accurate SEP onset measurements
- ~1kg mass, 3W power, on-board processing for low telemetry requirements
- (cf LISA PF RM: 1kg and 1.5W)

## SEP FLUX AT SMALL STEPS IN LONGITUDE ABOVE 100 MeV



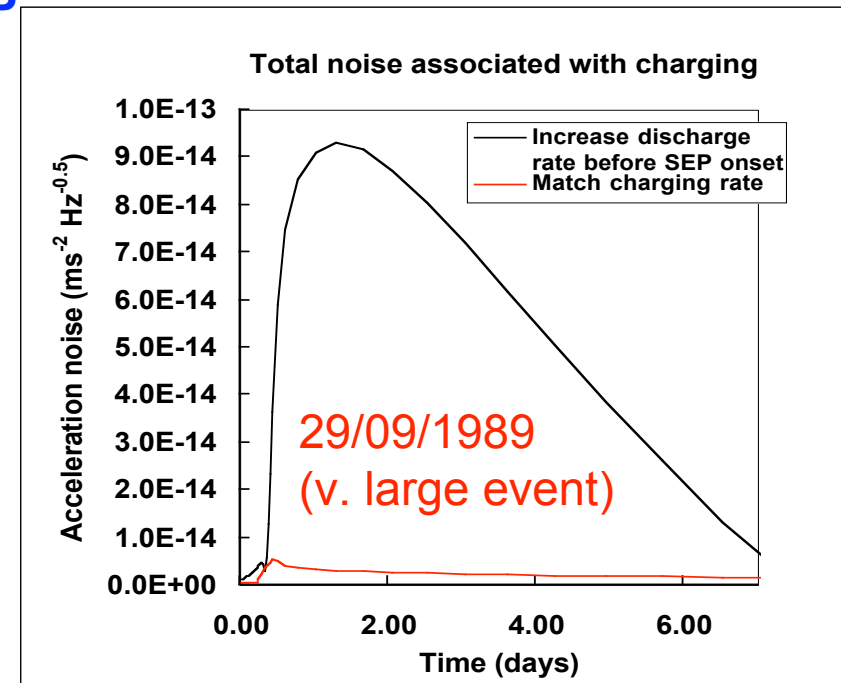
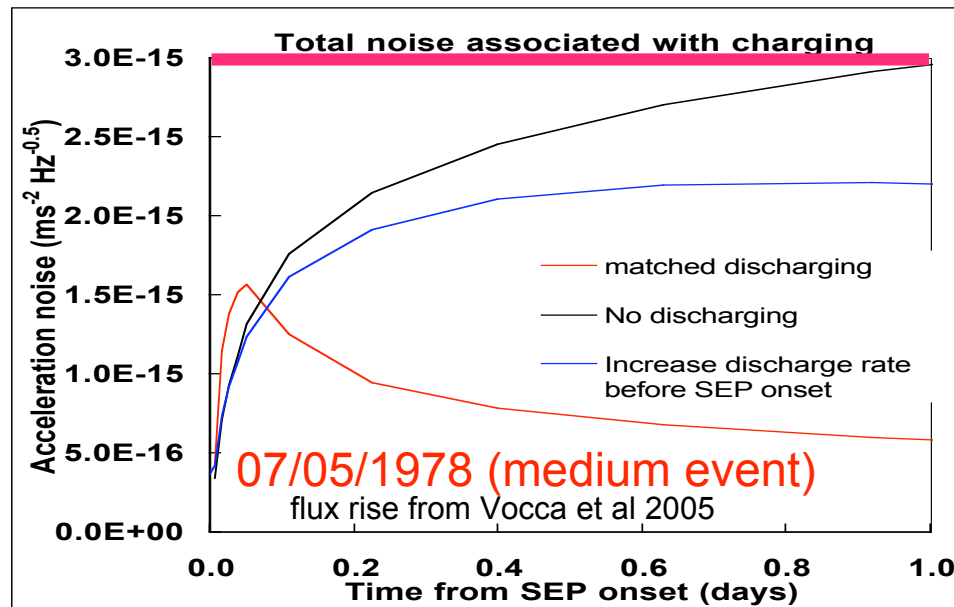
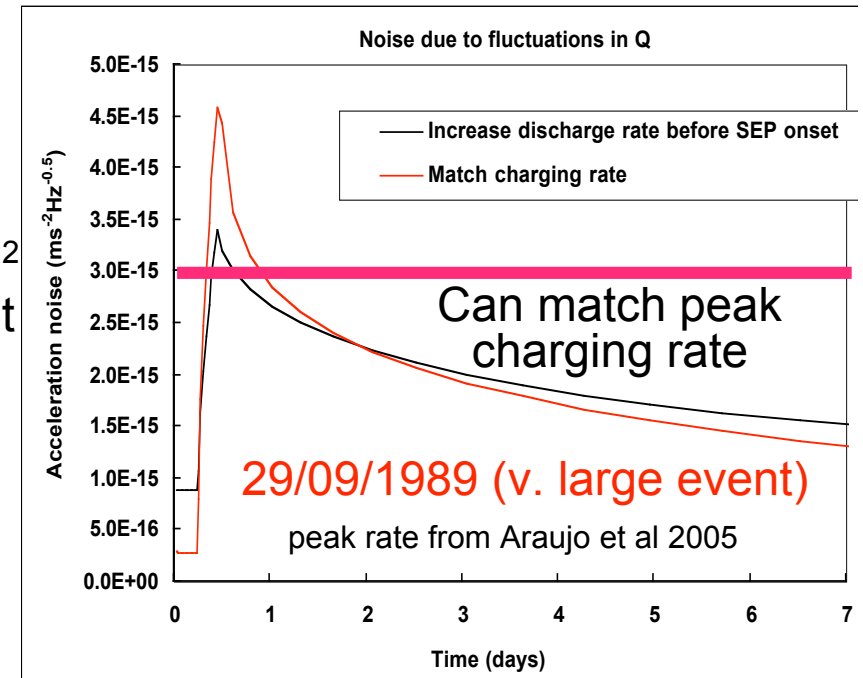
**We expect a SEP flux difference among the LISA satellites associated with the same event ranging between 5 and 10%.**

**This estimate was carried out on the basis of observed, energetic, proton fluxes related to gradual events differing by a few degrees in solar longitude.**

Further investigation is needed in order to take into account the role of different boundary conditions for each event.

# Charge management for SEPs

- **29/09/1989:**
- During SEP,  $\delta Q$  noise reduced by “pre-discharge”
- BUT, do not gain overall, due to terms  $\sim Q$ ,  $Q^2$
- If can match rate, charging noise  $\sim 1.5 \times$  target
- Data may still be useful for MBH mergers
- **07/05/1978:**
- For short time, more noise for matched discharge
- BUT overall, still better to match rate
- Total charging noise < LISA target  $\Rightarrow$  data potentially useful
- **Better understanding and prediction of SEP time profile will help to match rates**

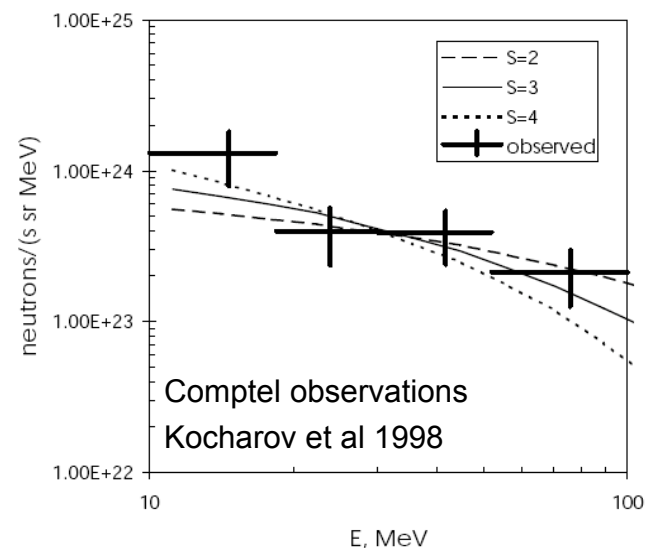


# **Additional particle fluxes**

## Neutron flux during solar flares

Large flares (X-class) produce neutrons, detected between 10 MeV and 10 GeV at 1AU.

Can penetrate and activate shield, and deposit momentum in test mass



Ballistic trajectories (*so, different set of events from the magnetically-connected SEP events*)

Flux =  $6-12 \times 10^{22} \text{ n} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$  in 10 -100 MeV range

$0.8 - 2.6 \text{ n} \cdot \text{s}^{-1}$  at TM, and noise due to momentum transfer  $\sim 10^{-19} \text{ NHz}^{-1/2}$

Neutron activation of shield/TM also not expected to be significant.

# LISA TM charging due to rare particles of solar, interplanetary and galactic origin with respect to protons (%)

## GALACTIC COSMIC-RAY NUCLEI

Element	$\lambda_{\text{net}}^{\text{m}}$ (% $\lambda_{\text{net,p}}^{\text{m}}$ )	$\lambda_{\text{eff}}^{\text{m}}$ (% $\lambda_{\text{eff,p}}^{\text{m}}$ )	$\lambda_{\text{net}}^{\text{M}}$ (% $\lambda_{\text{net,p}}^{\text{M}}$ )	$\lambda_{\text{eff}}^{\text{M}}$ (% $\lambda_{\text{eff,p}}^{\text{M}}$ )
C	2.4	9.3	4.6	5.5
N	1.1	2.1	<1%	<1%
O	3.2	13.8	4.6	7.8
Mg	<1%	<1%	<1%	<1%
Si	<1%	<1%	<1%	<1%
Fe	<1%	<1%	<1%	<1%

Grimani et al., CQG, 22, S327, 2005

## SOLAR ELECTRONS

Flare	$\lambda_{\text{net}}^{\text{m}}$	$\lambda_{\text{eff}}^{\text{m}}$
3/11/1973	<1%	<1%
7/09/1973	<2.7%	<1%

FLUKA 2006

## INTERPLANETARY ELECTRONS

$A < 0$	$\lambda_{\text{net}}^{\text{m}}$	$\lambda_{\text{eff}}^{\text{m}}$
	13%	1.5%
$A > 0$	$\lambda_{\text{net}}^{\text{m}}$	$\lambda_{\text{eff}}^{\text{m}}$
	15%	1.7%

FLUKA 2006

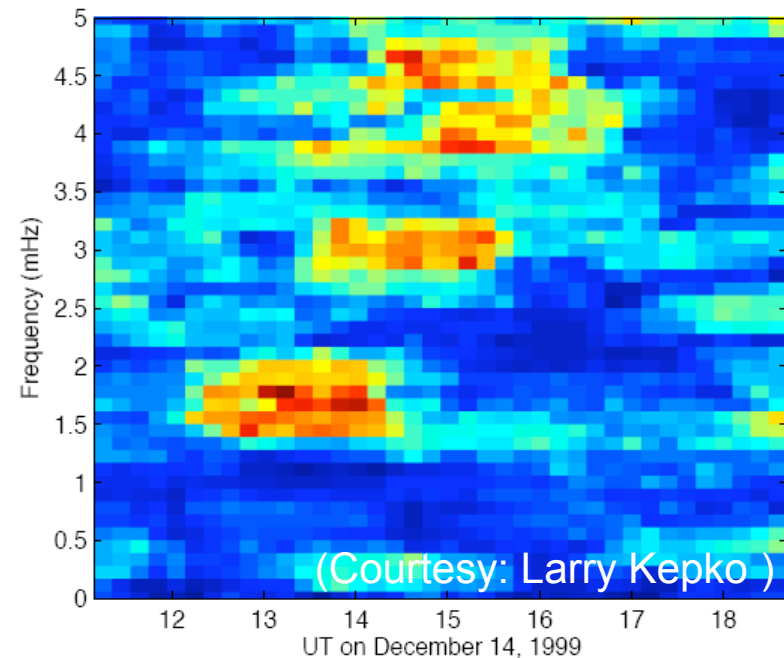
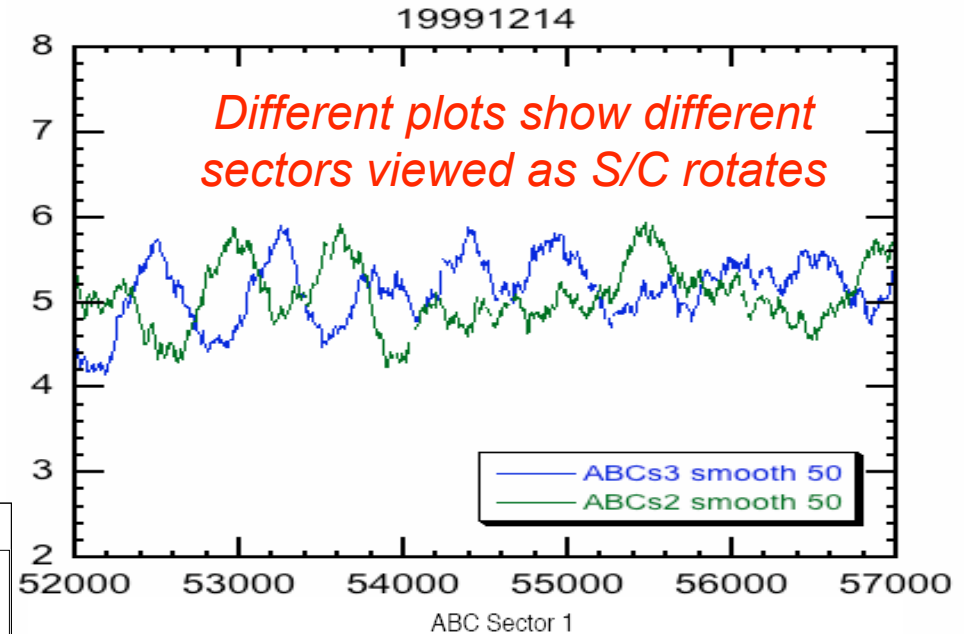
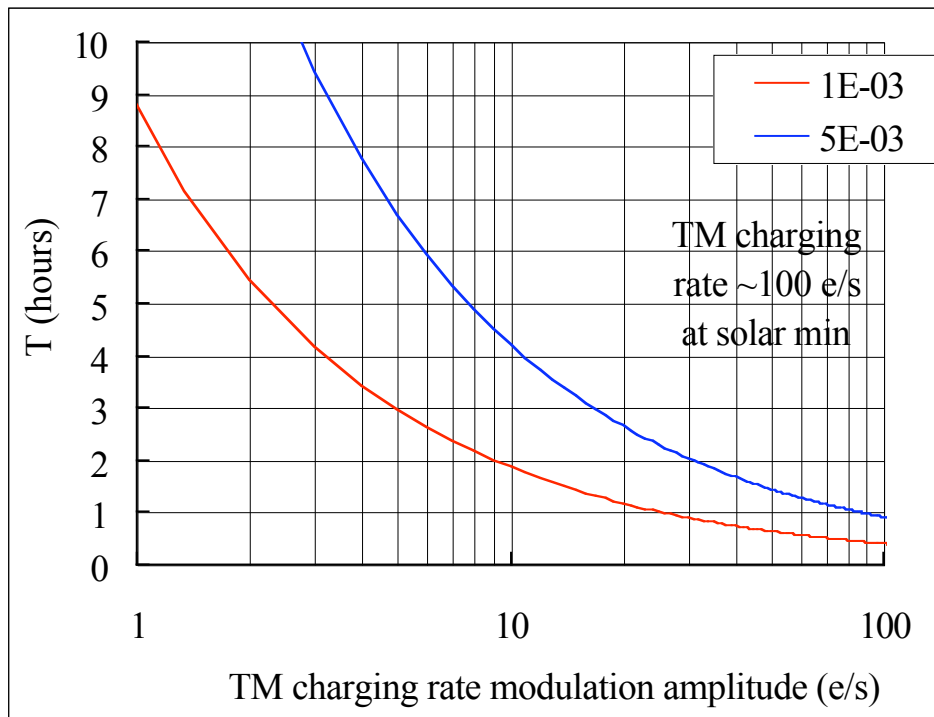
Same inside  
model and simulation errors

For absolute rates (p and He), see Araujo et al 2005

GCR variability:  
Other fluctuations  
(data from POLAR:  
>100MeV)

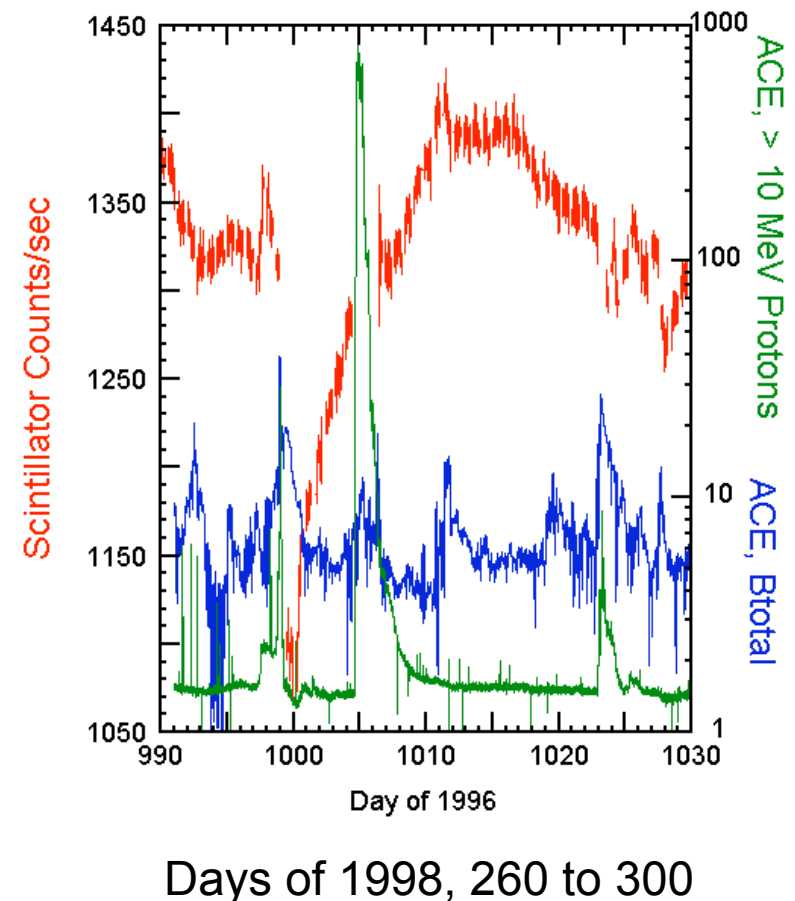
# Periodic GCR flux variations

- Distinct mHz variations apparent at certain times
- Fluctuations  $\sim 10\text{-}20\%$
- Will appear above LISA noise within  $\sim 1\text{-}4$  hrs
- Further investigation ongoing



# GCR variations contd

- Frequent  $\Delta I/I \sim \text{few \%}$  in  $\sim \text{few days}$
- Forbush event at day 269, 15% decrease
- Short term changes at day 261 for 7 days (4%) and 287 for 10 days (5%).
- Could be explained by passage of a magnetic rope (Quenby et al)



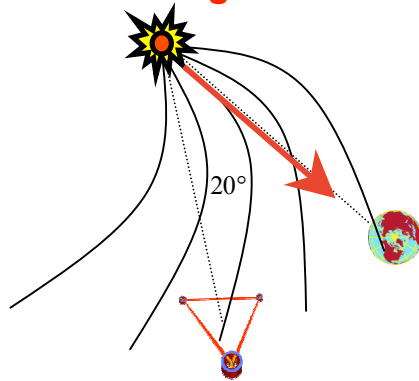
# Implications for LISA

- Fluctuations will modulate spectrum of coherent charging signals
- How well we can predict these signals will factor into how well we can remove them
- **CRaTER** (instrument on Lunar Reconnaissance Orbiter, to investigate the effect of galactic cosmic rays on tissue-equivalent plastics) and **LISA PF** (in particular) useful in further characterisation of these variations

**What LISA can do for us**

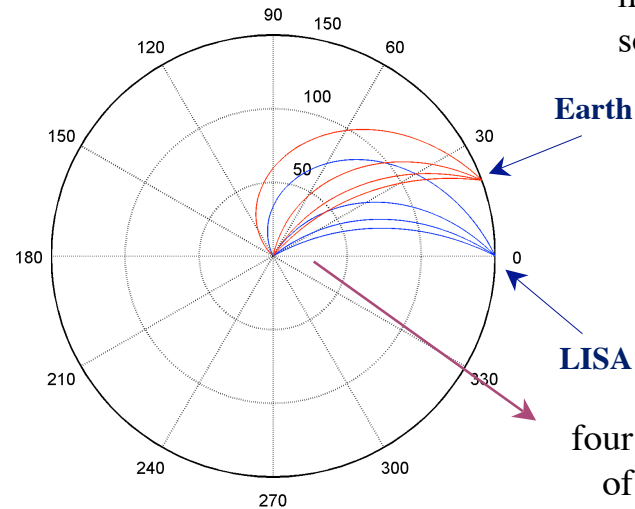
# Space Weather prediction with LISA

Use LISA radiation monitors to map transit of SEPs correlated to CMEs through the S/C



LISA will detect some CMEs before they reach Earth

Magnetic field lines through Lisa and Earth



The structure of the interplanetary magnetic field is a function of the solar wind speed:

$$r - r_0 = -\frac{v_{sw}}{\Omega}(\phi - \phi_0)$$

$v_{sw}$  = Solar Wind speed

$\Omega$  = Solar angular vel.

four MF lines for solar wind speed of 200, 400, 600 and 800 km/s

*Information on LISA can be used to predict SW on Earth.*

# Variation of GCR flux with Global Solar Magnetic Field polarity

- **Solar min:** Proton and He flux variations (40% at 100 MeV, 30% at 200 MeV, 25% close to 1 GeV - effect seen up to 4 GeV) - data from 2 contiguous solar cycles (Belov, Guschina & Yanke 1997, Durban ICRC, 2, 61; Boella et al. 2001, J. Geophys. Res, 106, A12, 29355)  
(=> For  $A < 0$ , solar min possible reduction in TM charging from GCR protons of 20% wrt estimates, but probably not during LISA or LISA PF windows)
- **Solar max:** No variations found
- Disagreement over whether any dependence of rare galactic particle fluxes (e.g. positrons, antiprotons) on solar polarity (Clem & Evenson 2004, J. Geophys. Res., 109, A07107, Beatty et al., astro-ph/0412230; Asaoka et al., Phys. Rev. Lett., 88(5), 051101 )
- The LISA and LISA-PF/CRaTER missions will give new insights if observe 2 opposite polarity changes while in orbit

# Summary

- **SEPs**
  - Duration < ~1.5 days; ~3.3/yr ( $\Rightarrow$  ~ 1% of time affected) but large spread in quiet time (1 day - ~1yr); flux difference between S/C ~ 5 -10%; work ongoing to improve predictions for LISA
  - If have charging rate = discharging rate, data potentially useful. Need accurate prediction/measurement of flux time evolution to minimize disturbances.
- **Neutrons**
  - Solar flare neutrons do not seem to be a problem
- **Electrons**
  - Interplanetary flux  $\Rightarrow$  significant TM charging
  - Could provide early warning for large SEPs
- **GCR variability (POLAR)**
  - mHz ~10-20% variations
  - Frequent  $\Delta I/I$  ~ few % in ~ few days also apparent
  - Will modulate spectrum of coherent charging signals
  - How well we can predict these signals will factor into how well we can remove them
  - Further investigation ongoing
- ***All being fed into full noise model for charging/discharging (model also folds in e.g. GRS and discharge system characteristics) –work in progress***
- **“Free Science”**
  - Evolution and Distribution of CME Energetic Particle Population
  - Galactic Cosmic Ray Fluctuations